CS368 MATLAB Programming

Lecture 7

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Based on lecture slides by Michael O'Neill and Beck Hasti

March 9, 2022

Coordination Game

Quiz

- No lecture next week.
- For the quiz grade next week (out of 2):
- A : If $\geqslant$ 95% of you chooses A, everyone gets 3 points.
- B : If $\geqslant$ 75% of you chooses B, everyone gets 2 points.
- C : If $\geqslant$ 50% of you chooses C, everyone gets 1 point.
- Otherwise, everyone gets 0.

Schedule

Admin

- No lecture next week.
- There will be office hours (all on Zoom).
- Code similarity check. Grade maybe changed to 0 if:

1. No code submission on Canvas (either .txt or .m). Allowed to resubmit.
2. Almost identical code without attribution. Not allowed to resubmit.

- Midterm grades on Canvas. Not going to submit official midterm grades.

Polynomials

Math

- A degree n polynomial, $c_n x^n + c_{n-1} x^{n-1} + c_{n-2} x^{n-2} + \ldots + c_2 x^2 + c_1 x + c_0$ is specified by a list of coefficients $c_n, c_{n-1}, \ldots, c_1, c_0$ usually stored in a vector.
- The computation can be done efficiently using Horner's method: $((((c_n x + c_{n-1})\, x + c_{n-2})\, x + \ldots + c_2)\, x + c_1)\, x + c_0$.

Exponential and Trigonometry Functions

Math

- Many elementary function can be evaluated and approximated using polynomials.

1. $e^x \approx 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \frac{x^4}{24} + \frac{x^5}{120} + \ldots$
2. $\sin(x) \approx x - \frac{x^3}{6} + \frac{x^5}{120} + \ldots$
3. $\cos(x) \approx 1 - \frac{x^2}{2} + \frac{x^4}{24} + \ldots$

- They are also called Taylor polynomials.

Polynomial Evaluation

Code

- Suppose c and x are row vectors with length n.
- *dot(c, x .^ ((n − 1):−1:0))* evaluates the polynomial with coefficients c at x.
- *polyval(c, x)* evaluates the same polynomial but faster.

Polynomial Evaluation, Trig

Quiz

- (Compute $\cos(x) \approx 1 - \frac{x^2}{2} + \frac{x^4}{24} + \ldots - \frac{x^{10}}{10!}$ at $x = 1$.)
- **0.5403**
- *C* : *polyval(((−1) .^ (5:−1:0)) ./ (factorial (10:−2:0)), 1)*

Lagrange Polynomial

Math

- A set of n points (with distinct x values) uniquely determine a degree $n-1$ polynomial that passes through all the points.
- The coefficients of the leading terms can be zero, so technically the degree of the polynomial can be less than $n-1$.

Lagrange Polynomial Diagram

Math

Vandermonde Matrix

Math

- The coefficients can be found by solving a system of linear equations, $\begin{bmatrix} x_1^{n-1} & x_1^{n-2} & \dots & 1 \\ x_2^{n-1} & x_2^{n-2} & \dots & 1 \\ \dots & \dots & \dots & \dots \\ x_n^{n-1} & x_n^{n-2} & \dots & 1 \end{bmatrix} \begin{bmatrix} c_{n-1} \\ c_{n-2} \\ \dots \\ c_0 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_n \end{bmatrix}$.

Polyfit

Code

- Suppose x, y are two row vectors with length n.
- `repmat(x', 1, n) .^ ((n - 1):-1:0)` is the Vandermonde matrix, and `vander(x)` creates the same matrix.
- `vander(x) \ y'` solves for the coefficients using the Vandermonde matrix.
- `polyfit (x, y, n - 1)` finds the same coefficients.

Spline

Math

- A set of n points (with distinct x values, and ordered according to x) can define $n-1$ cubic polynomial segments satisfying the following conditions.

1. The i-th polynomial segment connects point i and point $i+1$.
2. The segments form a smooth curve. Technically, C^2 smoothness is desired: the first and second derivatives should be continuous.

Spline Diagram

Math

Tridiagonal Matrix

Math

- With n points, there are $4n - 4$ coefficients to compute. Suppose the coefficient for segment i connecting (x_i, y_i) and (x_{i+1}, y_{i+1}) is $c_{i1}, c_{i2}, c_{i3}, c_{i4}$.

1. $c_{i1}x_i^3 + c_{i2}x_i^2 + c_{i3}x_i + c_{i4} = y_i$ for $i = 1, 2, ..., n-1$ so that the segment passes through the left end point.
2. $c_{i1}x_{i+1}^3 + c_{i2}x_{i+1}^2 + c_{i3}x_{i+1} + c_{i4} = y_{i+1}$ for $i = 1, 2, ..., n-1$ so that the segment passes through the right end point.
3. $3c_{i,1}x_{i+1}^2 + 2c_{i2}x_{i+1} + c_{i3} = 3c_{i+1,1}x_{i+1}^2 + 2c_{i+1,2}x_{i+1} + c_{i+1,3}$ for $i = 1, 2, ..., n-2$ so that the first derivative is continuous.
4. $6c_{i1}x_{i+1} + 2c_{i2} = 6c_{i+1,1}x_{i+1} + 2c_{i+1,1}$ for $i = 1, 2, ..., n-2$ so that the second derivative is continuous.

- There are $4n - 6$ equations. 2 more equations are needed.

End Point Conditions

Math

- There are many ways to specify the 2 extra equations.

1. If the third derivative for the first and last two segments are continuous, $c_{1,1} = c_{2,1}$ and $c_{n-1,1} = c\left(n-2,1\right)$, the resulting spline is called a not-a-knot spline.
2. If the second derivative at the end points are 0, or $6c_{1,1}x_1 + 2c_{1,2} = 0$ and $6c_{n-1,1}x_n + 2c_{n-1,2} = 0$, the resulting spline is called a natural spline.

Spline
Code

- Suppose x, y are two row vectors with length n.
- *spline (x, y). coefs* finds the coefficients of the cubic spline that interpolates (x, y) while satisfying the not-a-knot condition.
- *spline (x, y, x0)* evaluates the cubic spline interpolating (x, y) at $x = x_0$.
- *csape(x, y, ' variational '). coefs* finds the coefficients of the natural cubic spline. It requires MATLAB's Curve Fitting Toolbox.

Local Coefficient

Code

- *spline(x, y).coefs* are local coefficients meaning the equation for segment i and $x \in [x_i, x_{i+1}]$ is $c_{i1}(x - x_i)^3 + c_{i2}(x - x_i)^2 + c_{i3}(x - x_i) + c_{i4}.$
- The polynomial can be expanded to find the coefficients of the original spline problem.

Interpolation, Polyfit

Quiz

1. *x = 1:5; y = polyval(ones(5, 1), x); polyfit (x, y, 4)*

- B : **1 1 1 1 1**
- C : **0 0 0 0 1**

Interpolation, Polyfit Too

Quiz

1. *x = 1:5; y = 5:−1:1; polyval(polyfit (x, y, 4), x)*
   - *C* : **5 4 3 2 1**
   - *D* : **1 2 3 4 5**

Interpolation, Spline

Quiz

1. *x = 1:5; y = 5:−1:1; spline (x, y, x)*

- *C* : **5 4 3 2 1**
- *D* : **1 2 3 4 5**

Interpolation, Spline Too

Quiz

1. $x = 1{:}5;\ y = 5{:}{-1}{:}1;\ spline(x,\ y).coefs(:,4)$

- $C : \begin{matrix} \mathbf{4} \\ \mathbf{3} \\ \mathbf{2} \\ \mathbf{1} \end{matrix}$ $D : \begin{matrix} \mathbf{5} \\ \mathbf{4} \\ \mathbf{3} \\ \mathbf{2} \end{matrix}$

Polynomial Regression

Math

- *polyfit (x, y, d)* with $d < n$, finds the polynomial that is the closest to the points (x, y).
- The total distance from the points to the polynomial is defined as the sum of the squared differences between the y value at x and the value of the polynomial at x,

$$D = \sum_{i=1}^{n}\left(y_i - \sum_{j=0}^{d} c_i x_i^j\right)^2$$

$$= \sum_{i=1}^{n}\left(y_i - c_d x_i^d - c_{d-1} x_i^{d-1} - \ldots - c_1 x_i - c_0\right)^2.$$

- *polyfit* finds the coefficients of the polynomial that minimizes D. These coefficients are also called regression coefficients.

Regression Diagram

Math

General Linear Regression

Math

- *regress (y ', X)* finds the regression coefficients for $c_n x_n + c_{n-1} x_{n-1} + \ldots + c_1 x_1 + c_0 x_0$, where $x_0, x_1, \ldots, x_n$ are the columns of X. It requires MATLAB's Statistics and Machine Learning Toolbox.
- *regress (y ', X)* solves $\left(X^T X\right) c = X^T y$ instead of $Xc = y$. This is because $X^T X$ is always invertible (meaning $\left(X^T X\right)^{-1}$ always exists), so $c = \left(X^T X\right)^{-1} X^T y$.
- When X is the degree d Vandermonde matrix for x, meaning $x_i = x^i$ for $i = d, d-1, \ldots, 0$, *regress (y, X)* finds the same coefficients as *polyfit (x, y, d)*.

Non-Polynomial Regression

Code

- *polyfit (f(x), y, 1)* finds the regression coefficients for $c_1 f(x) + c_0$, for example, *polyfit (sin (x), y, 1)* finds c_1, c_0 such that the total distance from the points to the function $y = c_1 \sin(x) + c_0$ is minimized.
- *regress (y', [f1(x') f2(x') ...])* finds the regression coefficients for $c_1 f_1(x) + c_2 f_2(x) + \ldots$, for example, *regress (y', [sin (x') cos(x') ones(length (x), 1)])* finds c_2, c_1, c_0 such that the total distance from the points to the function $y = c_2 \sin(x) + c_1 \cos(x) + c_0$ is minimized.

Regression, Polynomial

Quiz

- (The values of c, d such that the curve $y = cx^2 + d$ best fits (x, y) .)
- **1 1**

1. *x = 1:10 ; y = 1 + x .^ 2;*

- A : *polyfit (x, y, 1)*
- B : *polyfit (x, y, 2)*
- C : *polyfit (x .^ 2, y, 1)*

Regression, Unknown Degree

Quiz

- (The values of c, d such that the curve $y = cx^d$ best fits (x, y) .)
- **1 1**

1. *x = 1:10 ; y = x;*

- A : *v = polyfit (log(x), log(y), 1); [exp(v(2)) v(1)]*
- B : *v = polyfit (x, log(y), 1); [exp(v(2)) v(1)]*
- C : *v = polyfit (log(x), log(y), 1); [v(2) v(1)]*
- D : *v = polyfit (x, log(y), 1); [v(2) v(1)]*

Regression, Non-Polynomial

Quiz

- (The values of c, d such that the curve $y = ce^{dx}$ best fits (x, y) .)
- **1 1**

1. $x = 1{:}10\ ;\ y = exp(x);$

- A : $v = polyfit(log(x),\ log(y),\ 1);\ [exp(v(2))\ v(1)]$
- B : $v = polyfit(x,\ log(y),\ 1);\ [exp(v(2))\ v(1)]$
- C : $v = polyfit(log(x),\ log(y),\ 1);\ [v(2)\ v(1)]$
- D : $v = polyfit(x,\ log(y),\ 1);\ [v(2)\ v(1)]$

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